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SPECIFICATION

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METHOD AND APPARATUS FOR GRINDING ASSEMBLED CAMSHAFTS WITH HIGH CONCENTRICITY ACCURACY

The invention relates to a method and an apparatus for grinding assembled camshafts with high concentricity accuracy in a grinding machine.

Assembled camshafts are assembled into a complete camshaft by joining individual parts in the work processes that precede grinding. The actual base body for the camshaft comprises a steel tube that as a rule is cold-drawn and that can additionally have depressions in areas between the individual cams. The cams are produced separately and for instance are shrunk onto the appropriate locations on the steel tube in a shrinking process, whereupon turning and milling processes can take place prior to the grinding. As a rule, the cams shrunken thereon are hardened in advance. Such assembled camshafts have the advantage that they enable a significant reduction in size compared to conventional cast camshafts. In order to optimize this reduction in mass, an attempt is made to keep the wall thickness of the steel tube as thin as possible. The thinner the wall thickness in the steel tube of the camshaft, the more such an assembled camshaft is then relatively unstable as a separate component. It is true that this instability is then somewhat eliminated when the camshaft is installed in the engine in that the camshaft is received and held in the sleeve bearings in the engine.

Another advantage of assembled camshafts is comprised in that different materials can be used for cams and bearings in order to be better able to take into account the different loads on the component.

Moreover, the assembled camshafts have the advantage that their production is also to an extent significantly more cost effective. For these reasons, assembled camshafts are being used more and more frequently in engines, it being recognized that, despite the relative stabilization when installed due to the sleeve bearings in the engine block, the demands for accuracy are growing, in particular demands for concentricity accuracy for the camshafts.

Due to the fact as described that the assembled camshafts are relatively soft with respect to their longitudinal axis in terms of bending, special demands are placed on the grinding process for them and on their chucking during grinding. Two principle process variants are known when grinding the bearings for the assembled camshafts. First, a so-called centerless grinding process is used to grind the bearings, and second, the bearings are ground such that the camshaft is gripped between centers and the bearings are ground one after the other, parallel or partially parallel. Since in this last known grinding method steadies are used when the bearings are ground, relatively good concentricity is attained with respect to the bearings arranged at the shaft ends (outer bearings), in particular for the inner bearings, i.e., the bearings arranged in the center area of the camshaft. Today concentricity requirements of for example 4/100 mm and less are demanded that have to be maintained with certainty.

Processing, i.e. grinding, of such assembled camshafts occurs in one or a plurality of chuckings. If it is possible to chuck the camshaft at the same locations, it is not important for the final quality of the produced camshafts whether the work is performed with two or more chuckings or even with one chucking. Another problem with assembled camshafts is that during grinding of the bearings and the cam shape the workpieces become out of true because of the energy added,

because of the grinding process itself, and because of the grinding of the hardened surfaces of the cams. This process is known per se. In those workpieces that have been joined cold and that have been hardened on their surfaces such as for instance the cam surfaces, these influences release at least some of the tensions contained in the material during grinding. These tensions then lead to the shaft becoming out of true. This means that the camshaft is no longer straight after grinding, that is, a so-called runout occurs that in particular is increased at the inner bearings, even if only by a few hundredths of a millimeter. This increase in the runout is ultimately responsible for the camshaft no longer staying within the required tolerances with certainty.

It is therefore the object of the invention to create a method and an apparatus for grinding assembled camshafts with concentricity properties that are improved relative to the accuracies that have been attainable in the past.

This object is attained using a method with the features in accordance with claims 1, 5, and 6, as well as with an apparatus with the features in accordance with claim 19. Useful further developments are defined in each of the subordinate claims.

Using the inventive method and the inventive apparatus, what is advantageously achieved is that the distortion on the finished camshaft is significantly reduced or even eliminated altogether. In the inventive method, in accordance with a first aspect the grinding of bearings and cams of assembled camshafts as well as the straightening of these camshafts is performed on a grinding machine, and specifically the straightening is also performed on this grinding machine after a grinding process. Preferably the grinding process is either finish-grinding of the

bearings and/or rough-grinding of the cams and/or finish-grinding of the cams. In accordance with one further development of the invention, the method steps of finish-grinding the bearings, rough-grinding and finish-grinding the cams, and straightening are performed in a single chucking.

In accordance with another aspect of the invention, the bearings of an assembled camshaft are first finish-ground on a first grinding machine and then the cams of the camshaft are rough-ground on a second grinding machine and are also finish-ground on this grinding machine, the camshaft being straightened on this second grinding machine after the rough-grinding and/or after the finish-grinding.

In accordance with another aspect of the invention, the bearings of an assembled camshaft are finish-ground on a first grinding machine and straightened on the same grinding machine, whereupon the rough-grinding and the finish-grinding of the cams of the camshaft occurs on a second grinding machine. Naturally it is possible that another straightening process can take place on the second grinding machine. This straightening process can occur prior to the rough-grinding and/or after the finish-grinding of the cams. However, in accordance with the invention, preferably only a single straightening process is performed.

For grinding bearings and cams of assembled camshafts on a grinding machine, during the grinding of the bearings the camshaft is preferably supported at bearings in particular on steadies, the bearings first being finish-ground and then the supports, i.e., the steadies, used during the grinding process being released. Following this in a preferably second method step the bearings are measured for concentricity accuracy, especially in the center area of the camshaft. The measured concentricity value or the deviation from ideal concentricity is

preferably stored and is used in a subsequent method step to straighten the camshaft on the same grinding machine on this basis. Not only is the concentricity improved with this straightening, but also the deviation from ideal concentricity can even be nearly eliminated. This additional step of straightening can occur after the finish-grinding of the bearings and/or preferably after the rough-grinding of the cams and/or after the finish-grinding of the cams. The bearings can be used for introducing the forces necessary for the straightening process. These straightening forces can also be introduced next to the bearings, in any case into the steel tube.

In a component like a camshaft with sections that are divided in the axial direction, as is known the maximum deviation from concentricity generally occurs in the center area. Therefore the bearing(s) is/are measured for concentricity in the center area of the camshaft. Then the straightening forces for attaining the most ideal possible concentricity are introduced in the area of these bearings. In the following, concentricity shall be understood in particular to be the concentricity of the inner bearings to the outer bearings and of the bearing to the base circle of the adjacent cam or pair of cams.

In accordance with the invention, it is important that a straightening process is inserted between different grinding operations. However, it is also possible to perform such a straightening process after the conclusion of the last grinding process. In any case, it is necessary to re-compensate the concentricity properties that have degraded during grinding of the bearings and/or cams as a result of the tensions released in order to attain greater accuracy, i.e. greater precision in the concentricity properties of the camshaft in the area of the center bearings with respect to the end bearings of the camshaft. In addition, the bearings are finish-

ground. In a further step the cam shape can be rough-ground, a straightening process following this that is itself followed by a finish-grinding process for the cams. A straightening process can again follow this. However, preferably a single straightening process is used.

If the straightening process occurs after the rough-grinding of the cams on the camshaft, preferably the supports in particular in the form of steadies are again placed against the bearings, whereupon the finish-grinding of the cams takes place.

Preferably the straightening is performed with the camshaft rotating, the camshaft rotating in particular at a speed of 50 – 200 min^{-1}. The actual straightening at this given speed is preferably attained by applying a pressure force to the center bearing of the camshaft. In this roll straightening process, it is not entirely necessary to measure the camshaft with regard to concentricity accuracy because the camshaft is loaded beyond the yield point of its material during straightening.

In order to be able to bring about the straightening process effectively, preferably the straightening occurs on the camshaft preferably at least by area beyond the yield point of the material of its steel tube. "By area" shall be construed in the following in particular to mean that during the roll straightening corresponding to about one walk process at least areas of the steel tube are rendered largely low-tension in the structure by remaining deformations. I.e., the material of the camshaft is subjected to pressure, whereupon there is a gradual removal of the bend in the camshaft to essentially 0 mm. The pressure force exerted is thus reduced gradually so that the bend is also reduced.

However, in accordance with another preferred exemplary embodiment, it is also possible for the straightening to occur with a stationary camshaft. In this case the deviation from ideal concentricity is also initially determined at a bearing, specifically the bearing that has the greatest deviation from ideal concentricity is measured. As a rule this will be a bearing in the center area of the camshaft. When measuring, the greatest runout is determined, i.e. the radial position at which the deviation from concentricity is the greatest. Then the pressure force is introduced at this radial site, intentional bending of the camshaft being produced with this pressure force. The introduction of the pressure force and the reduction in the amount of this pressure force is matched to the actually measured value of the concentricity deviation at the bearing in question.

If all of the method steps are to be realized in a single chucking in accordance with the first aspect of the invention, an apparatus for performing the method in such a case has a grinding machine with an appropriate number of grinding spindles and one straightening device. This has the advantage that re-chucking operations are not necessary and the care is not required that would otherwise necessitate additional complexity and additional costs to ensure nearly identical gripping conditions if there was re-gripping. Surprisingly, it has now been demonstrated that the desired results in terms of high accuracy in concentricity properties of assembled camshafts can be achieved even when the camshaft is again re-chucked on one grinding machine with a plurality of work stations after the bearings have been finish-ground or after the cams have been rough-ground and the straightening process is then performed in the second chucking, but on the same grinding machine. If at least nearly identical gripping conditions can be attained during re-chucking, re-chucking can occur even between any desired method steps.

Moreover, a concentricity measuring device is preferably integrated into the grinding machine of the inventive apparatus. A concentricity value or concentricity deviation value is determined with this concentricity measuring device. The concentricity measuring device is preferably connected via a control device to the straightening device so that the straightening device is optimally controllable based on the measured concentricity deviation value for the straightening process, specifically such that the concentricity deviation is at least largely eliminated after straightening.

In accordance with the first aspect of the invention, the method occurs on a single grinding machine. However, this grinding machine can have two stations. The bearings are finish-ground at the first station of this grinding machine. On the other hand, the cams of the camshaft are rough-ground and finish-ground at the second station. However, it is also possible for the rough-grinding of the cams to be performed at the first station of the grinding machine, whereupon the cams are finished-ground at the second station of this grinding machine. The method step of straightening the camshaft can then occur after the rough-grinding of the cams at the first station. However, it is also possible to perform the straightening method step subsequent to the finish-grinding of the cams at the second station. Regardless of whether the camshaft is straightened in the same chucking or the straightening is performed at the first station or at the second station of the grinding machine, the straightening process lasts approximately 5 to 15 seconds. This means that the straightening process itself is significantly faster then a second grinding pass. In addition, unit costs are substantially reduced because of the straightening. Considering the fact that camshafts are always required in relatively high numbers, unit costs play a significant role in terms of the efficiency of the method. Surprisingly, it has now been demonstrated that very good results

can be attained in the relatively brief period of 5 to 15 seconds in terms of improving concentricity properties compared to concentricity properties that can be attained with conventional technologies.

In accordance with the second and the third aspect of the invention, the finish-grinding occurs on a first grinding machine and the rough-grinding and finish-grinding of the cams occur on a second grinding machine. In each case, the method is at least partially realized on at least one grinding machine such that one grinding process and one straightening process are performed on this grinding machine. This can be straightening of the camshaft after the bearings have been finish-ground on the first grinding machine. However, this can also be straightening after the cams have been rough-ground and/or finish-ground on the second grinding machine. However, it is also possible for straightening to occur both on the first grinding machine after the bearings have been finish-ground and after the rough-grinding and/or finish-grinding on the second grinding machine.

In accordance with another aspect of the invention, for grinding bearings and cams of an assembled camshaft and for straightening such an assembled camshaft, and specifically in particular for performing the method according to the corresponding method claims, in accordance with the invention the apparatus has a grinding machine that is provided with a straightening device for straightening the camshaft after a corresponding grinding process and preferably is also provided with a concentricity measuring device for measuring the concentricity or the concentricity deviation of the camshaft. The concentricity measuring device, if one is present, and the straightening device are inventively integrated into the grinding machine. The apparatus in accordance with the invention is a grinding machine, the actual grinding task of which has been expanded to include a

straightening process, the concentricity measuring device preferably additionally being integrated into this grinding machine. It is used for controlling the straightening device, i.e. for performing the straightening based on the measured concentricity value or the measured concentricity deviation. It is thus possible to produce with such an apparatus assembled camshafts whose base carrier is a hollow shaft onto which the cams are pressed in particular in a joining method with greater precision with respect to their concentricity properties than is the case with the known grinding machines that are not provided for the straightening step. It is only with the inventive apparatus that straightening can be performed after a grinding process within the same modified grinding machine. Concentricity properties or deviations in concentricity properties shall be understood to be how severely the bearing(s) deviate(s) in the center area of the camshaft with regard to their concentricity relative to the longitudinal axis of the camshaft from the concentricity of the bearings at the end of the camshaft. These end bearings are of course subjected far less to the concentricity deviations than the bearings arranged in the center or in the center area of the camshaft because the end bearings are each gripped, specifically on the centers of the grinding machine.

The central part of the inventive apparatus, specifically the grinding machine, has in a manner known per se a grinding headstock that is borne on a machine bed and that can have two grinding wheels that can each be pivoted into a grinding position and that can have a workpiece headstock and tailstock received on a grinding table. The assembled camshaft can be gripped between the centers of the workpiece headstock and tailstock. The concentricity measuring device is preferably on the grinding headstock or on the grinding table and is attached in the straightening direction to the grinding headstock.

Attaching the concentricity measuring device to the grinding headstock or to the grinding table assures high measurement accuracy because the measurement value is always coupled to the grinding result obtained by the respective grinding wheel. This also applies for the straightening device, which, by its arrangement on the grinding headstock, assures that, in conjunction with the highly precise measurement value for the concentricity deviations, a straightening force can be applied correspondingly to the camshaft and thus high precision can be attained in the straightening process with the inventive apparatus.

In accordance with a preferred further development of the invention, the grinding machine of the inventive apparatus has a first station for grinding the bearings and/or rough-grinding the cams of the camshaft and in which a straightening device can also be provided for straightening the camshaft. Moreover, the second station for finish-grinding the cams of the camshaft is also provided with a straightening device. The grinding machine of the inventive apparatus thus can have, but does not have to have, a first station in which a straightening device can be provided. A straightening device is preferably also provided in the second station so that the straightening or where necessary the final straightening of the camshaft can be performed after the cams have been finish-ground. Naturally, in principle it is also possible to divide the grinding process into two parts so that after the cams have been rough-ground the straightening device is used and so that also after the cams have been finish-ground the straightening device provided on the second station can be used. The first station and also the second station preferably have a straightening device for this purpose. The grinding machine of the inventive apparatus thus has complete flexibility. However, it is also possible for the first station to be embodied such that the bearings can be ground on it and the cams of the camshaft can be rough-ground on it, the straightening device then

being used either after the bearings have been ground or after the subsequent rough-grinding of the cams on the camshaft. Then only the finish-grinding of the cams of the camshaft occurs in the second station of the grinding machine of the inventive apparatus, whereupon another straightening process, a so-called final straightening process, can preferably follow. However, regardless of how the grinding processes and straightening are divided between the first and the second stations, there is preferably an attempt to attain the required concentricity accuracy in the assembled camshaft with a single straightening process. It is also possible that the straightening device for the first station is not used after the rough-grinding and only the straightening device for the second station performs a single straightening process after the finish-grinding of the cams.

The straightening device is preferably a roll straightening head that is embodied such that straightening can be performed when the camshaft is rotating. The rotation speed during the roll straightening process performed by means of the roll straightening head is preferably in the range of 50 to 200 revolutions per minute. The roll straightening head preferably has rolls borne in its forward area. "Forward area of the roll straightening head" shall be understood to mean the area that is oriented directly toward the area of the corresponding bearing on the camshaft to be straightened. The roll straightening head is preferably attached to the grinding headstock and preferably can be moved in the X-direction toward the bearings of the camshaft. The movement of the roll straightening head toward the bearings depends on the concentricity deviations measured by the measuring device at the bearing in question and thus determines the force to be exerted on the camshaft at this bearing in order to be able to completely perform this straightening process such that after straightening has been performed the camshaft has the most ideal possible concentricity, i.e., ideal concentricity

properties.

It is understood that appropriate calculation and control devices are provided for the control technology connection between the measuring device and the straightening head, including the appropriate actuators for converting the measured value to the corresponding force introduced for desired bending. The measuring is preferably not necessary when there is roll straightening. The straightening head is embodied such that it gradually reduces, i.e., decreases, the straightening force after the latter has been introduced. The force that is exerted with the roll straightening head on the appropriate bearing of the camshaft can be set high enough that the elastic deformation range is exceeded so that a straightening effect actually occurs using plastic deformation. Using a gradual, thus gentle, adjustment to , i.e., reduction in, the straightening force applied, the straightening process can be gradually terminated during straightening while the camshaft continues to rotate. This means it is possible to impart the desired straightening effect to the center area of the camshaft, which is subject to the most severe deformation.

In accordance with another preferred exemplary embodiment, the straightening device is embodied as a pressure element straightening head that performs the straightening while the camshaft is stationary. During straightening performed with a stationary camshaft, the measuring device cooperates in terms of control technology with the straightening head via appropriate electronic devices. First the measuring device determines the value at which the corresponding bearing, seen in the radial direction at the respective bearing, has the greatest runout and thus the greatest concentricity error. And it is at this precise location or in this area of the greatest runout on the bearing of the camshaft that the force is

introduced by means of the pressure element straightening head. This force is adjusted as a function of the measured runout such that the deformation goes into the plastic range so that a lasting straightening effect is present. The straightening head can be embodied such that this straightening effect is attained in a single straightening process. However, it is also possible to perform the straightening process in a plurality of steps, whereby different forces can then be introduced at different radial positions for eliminating the runout existing in the area of the bearing in question.

The pressure element straightening head is preferably embodied as a borne prism having a recess by means of which a certain area of the circumference of a corresponding bearing of the camshaft can be enclosed, whereby a desired straightening force is introduced across the circumferential area via at least two circumferentially spaced locations of one bearing of the camshaft. However, it is also possible to configure the prism such that during the straightening process the two lateral flanks and the base of the prism are positioned at the location on the circumference of the bearing such that the straightening force is then introduced via three locations. Matching the shape of the prism to the diameter of the bearing to be ground in this manner has the advantage that it enables effective straightening, in particular when there is major runout.

In addition, it is preferably possible that the pressure element straightening head is a pressure element that has an essentially flat surface for applying the straightening force. The corresponding straightening force can be introduced via a location on a bearing of the camshaft with the pressure element. Other shapes are of course also conceivable instead of the flat surface or the prism, such as for

instance a curved shape, the radius of which is greater than the radius of the corresponding bearing.

Additional advantages of and potential applications for the invention shall now be explained in greater detail using the description with respect to the attached drawings.

Figure 1 depicts an assembled camshaft that is chucked between centers and the bearings of which are ground like this;

Figure 2 depicts a camshaft that is chucked between two centers and the cams of which are being ground;

Figure 3 depicts an apparatus in accordance with the invention with two stations, each for grinding and straightening the camshaft;

Figures 4a through d depict the essential method steps in the inventive method;

Figure 5 depicts a roll straightening head of the inventive apparatus at a bearing of the camshaft;

Figure 6 depicts a pressure element straightening head with swing-mounted prism during straightening at a bearing on the camshaft;

Figure 7 depicts a pressure element straightening head with planar surface during straightening of a bearing; and,

Figure 8 depicts the principle of another exemplary embodiment for the method or apparatus in accordance with the invention.

Figure 1 is a principle depiction of the chucking of an assembled camshaft 1, with corresponding bearings 2 and shrunk-on cams 3, that is held between centers 14. The centers are arranged on the workpiece headstock 12 and on the tailstock 13. The centers 14 are embodied such that they grip the tube-shaped carrier of the camshaft in the center and at these ends attain a corresponding clamping effect so that a torque can be transmitted to the camshaft and so that the tension is not high enough however that the camshaft will be deformed simply because of the clamping. Two grinding wheels 23, 24 are depicted that are arranged on a common grinding headstock 7 and that are moved into the grinding position for grinding respective bearings 2 on the camshaft 1. A steady 11 is arranged opposite the grinding wheel 23 for providing support during the grinding process. The support of the steady 11 ensures that the grinding forces applied during grinding to the bearing L2 of the camshaft 1 do not lead to deformation of the camshaft. Another steady 11 is positioned at a location that is not currently being ground. Moreover, the grinding wheel 24 is in contact at a bearing L5. A corresponding straightening device is not drawn in.

Figure 1 illustrates the first method step, in accordance with which the bearings 2 on the camshaft 1 are finish-ground first. All of the bearings 2 must be finish-ground before a straightening process or first straightening process can be performed.

Figure 2 depicts a condition during the process in which the cams are ground by grinding wheels 9, 10. The grinding wheel 9 rough-grinds the cams and the

grinding wheel 10 finish-grinds the cams. Steadies 11 support the bearings. The grinding wheels 9, 10 are embodied such that pairs of cams that enclose a bearing between them are ground simultaneously. Analogous to Figure 1, the camshaft 1 is also received between centers 14 of the workpiece headstock 12 and the tailstock 13. A chuck 28 is attached to the workpiece headstock for radially carrying the camshaft 2.

Figure 3 depicts an apparatus in accordance with the invention in which the grinding machine comprises a first station 15 and a second station 16. In the first station 15, a camshaft 1 is gripped on centers between a workpiece headstock 12 and a tailstock 13. Gripping is performed via centers 14 on the workpiece headstock 12 and on the tailstock 13. Steadies 11 are moved to bearings of the camshaft 1 for supporting the latter. The steadies 11 can be moved to the respective bearing for support using a displacement in the X-direction. A grinding headstock 7 is arranged on a machine bed 8 opposing the steadies 11. The grinding headstock 7 can be pivoted and there are two spindles, of which a first spindle bears a first grinding wheel 9 and a second spindle bears a second grinding wheel 10. Pivoting the grinding headstock 7 pivots the respective grinding wheels 9, 10 into the grinding position for grinding the bearings. The bearings are finish-ground in the first station 15.

Arranged on the grinding headstock 7 is a concentricity measuring device 5 that can be moved into a measuring position in the center area of the camshaft by pivoting the grinding headstock 7. After the concentricity measuring device 5 has been pivoted into its measuring position, it determines at a bearing to be measured the bearing's concentricity properties or the deviation from ideal concentricity. For purposes of ease of understanding, the straightening device is only drawn in

schematically at the first station 15. The concentricity measuring device 5 controls the straightening device based on the measured values for the concentricity of the measured bearing in the center area of the camshaft such that with it a force is introduced to the camshaft after the steadies 11 have been moved out of their supporting position for the bearings such that the camshaft is straightened and thereafter has improved concentricity properties. The forces introduced are high enough that the camshaft is brought closer to or even into its ideal concentricity properties by means of a lasting plastic deformation. The straightening preferably occurs after the finish-grinding process for the bearings in the first station 15 has concluded, specifically in the same chucking, and lasts approx. 5 to 15 seconds. This is especially advantageous in particular for large numbers of units in mass production as is the case for camshafts.

In principle, however, it is possible to omit a straightening process after the bearing grinding in the first station 15 if the straightening is performed after the rough-grinding or finish-grinding in the second station 16. The advantage of straightening at the end of the finish-grinding process for the cams is comprised in that it is then also possible to use the straightening to eliminate the deformations that occur because during grinding of the hardened surfaces of the cams tensions are released that can contribute to deformations on the entire camshaft. The basic structure of the second station 16 is the same as that of the first station 15, the first station 15 and the second station 16 being combined into a single grinding machine 4. This is a conventional modular structure, so that the advantage of the inventive apparatus is particularly noteworthy because as a rule the straightening occurs in the same chucking as the respective grinding process. The second station 16 also has a grinding headstock 7 that is borne on a machine bed 8. The grinding headstock 7 has two spindles for each grinding wheel 9, 10. Provided on

the grinding headstock 7 in the area of the grinding spindle for the grinding wheel 10 is a concentricity measuring device 5 that is arranged such that when the grinding wheel 10 is pivoted into its grinding position for finish-grinding the cams the concentricity measuring device 5 can be moved to a bearing in the center area of the camshaft. Measuring the bearing in the center area of the camshaft is especially sensible and necessary because that is where the distortion of the camshaft is the most severe. For reasons of simplicity the straightening device is also only drawn in schematically here in the second station 16, as well. Naturally this concentricity measuring device 5 is also connected via a control device (not shown) to the straightening device in order to be able to determine the straightening force corresponding to the shaft distortion and in order to be able, after applying this straightening force, to remove the straightening device from straightening contact with the camshaft while gradually reducing the force applied.

The camshaft 1 itself is held between centers 14 in a chuck 28 of the workpiece headstock 12 on the one side and in a corresponding center 14 of the tailstock 13 on the other side. The camshaft 1 itself is supported at its bearings by one of the number of steadies 11 corresponding to one of the number of bearings. In addition, a dressing device 25 is arranged in the second station 16 for dressing the grinding wheels 9, 10.

Figure 4 is a principle depiction of the camshaft 1 held between centers 14 for different method steps that are performed in the inventive apparatus. The camshaft 1 held between centers 14 is supported at its bearings 2 by means of steadies 11 located between cams 3 (Figure 4a). The bearings 2 have already been finish-ground so that the steadies 11 have been moved supportively against the

finish-ground bearings on the camshaft 1. The cams 3 are rough-ground in this supported condition. What the support with the steadies 11 attains is that, despite applying the grinding forces to the cams 3, during grinding of the cam shape the deformation of the camshaft 1 due to the grinding processes is limited.

After the cams 3 have been rough-ground, in accordance with Figure 4b) the steadies 11 are removed from contact with the camshaft 1. The camshaft 1 chucked between centers 14 is rotating and during its rotation is measured by means of the concentricity measuring device 5 for its concentricity or for deviations from concentricity. This measurement is made at the center-most bearing of the camshaft because it is here that the expected concentricity deviation is greatest.

After the concentricity measuring device 5 has determined the value for the concentricity deviation at the center-most bearing, a signal corresponding to the measured value is fed to a control device for the straightening device 6. With the steadies 11 no longer in contact, the straightening device 6 is moved to the center bearing of the camshaft 1 based on this signal that reflects the concentricity deviation. The force introduced to the camshaft 1 by means of the straightening device 6 is selected such that it is greater than the yield point of the material of the camshaft in order to attain a lasting deformation, including the desired straightening effect. The deformations that occur as a result of introducing grinding forces and as a result of the inner tensions released during grinding are compensated by the straightening. The concentricity measuring device 5 is preferably not used when roll straightening is used.

When the straightening process in accordance with Figure 4c) has been performed after the cams have been finish-ground, which is performed for instance in the second station 16 of the grinding machine 4 (see Figure 3), then Figure 4a) depicts the condition in which the finish-grinding of the cams, with simultaneous support of the appropriate bearings by steadies 11, occurs or has already concluded. In this case, after the straightening process in accordance with Figure 4c) has concluded, the camshaft is finished with the greatest precision in terms of its concentricity properties and can be removed from the grinding machine 4 or from the second station 16 of the grinding machine 4.

If the processes depicted in accordance with Figures 4a) through 4c) apply to a case in which the cams have first been rough-ground, whereupon the straightening occurs, it is naturally necessary to perform another method step with the inventive apparatus. This is depicted in Figure 4d), in which the steadies are again moved against the corresponding bearings so that the finish-grinding process for the cams 3 can then take place. The actual grinding processes and the grinding wheels are not shown in Figure 4 for the sake of clarity, since the principle structure of the grinding machine can be seen in Figure 3. Naturally a straightening process in accordance with Figure 4c) can follow the finish-grinding of the cams 3 in accordance with Figure 4d).

Figure 5 depicts an exemplary embodiment for a straightening device for a case in which for straightening the camshaft is received between the centers 14 of the workpiece headstock 12 and the tailstock 13 and is rotationally driven during straightening. For this, the straightening device is embodied as a roll straightening head 17 that has two borne rollers at its forward end. This roll straightening head 17 with its borne rollers 18 fits the contour of a camshaft 1 in

the area of its bearings. The straightening device can be moved in the X-direction toward the camshaft so that when the camshaft 1 rotates and the roller straightening head 17 simultaneously applies pressure with is rollers 18, the camshaft can be deformed such that it is subjected to pressure beyond the yield point of its material. The straightening forces are thus introduced into the camshaft 1 via the rollers 18, which also rotate with the rotation of the camshaft, at the locations where the rollers 18 contact the respective bearing. After the maximum straightening force has been introduced into the appropriate area of the bearing of the camshaft 1, the bend in the workpiece is then reduced by gradually withdrawing this roll straightening head 17 to a bend value of 0 mm for the workpiece. Rotationally symmetrical shafts can be straightened relatively quickly and certainly using this roll straightening process. In particular, this method can also be employed on the grinding machine 4 of the inventive apparatus because it is very rapid. Such a roll straightening method lasts approx. 5 to 15 seconds. This is significantly shorter than a second grinding process that would otherwise have to be performed and with which the concentricity properties that are attained using the inventive apparatus or the inventive method still could not be attained.

Figure 6 depicts another exemplary embodiment of a straightening device. In this case it is a straightening device that is suitable for a pressure straightening method. Such a pressure straightening method takes place when the shaft is stationary. In this case, first the concentricity or the deviation from concentricity is measured at the center bearing of the camshaft or at a bearing in the center area of the camshaft. Using this measurement, the “highest point” in the bearing circumference is measured in order to be able to determine the radial position at which this maximum concentricity error occurs. With this pressure straightening process, the camshaft 1 is now bent against its maximum deflection such that this

maximum deflection is eliminated as completely as possible. This straightening process can also occur in the chucking of the workpiece between the centers, whereby after determining the maximum deflection, i.e. the maximum concentricity error, the camshaft is rotated radially such that a pressure element straightening head 19 is placed in the X-direction in this area of the circumference of the corresponding bearing of the camshaft 1 against the camshaft such that an appropriate straightening force can be exerted against the latter. The pressure element straightening head 19 has at its forward side a borne prism 20 that has a recess 21 so that a circumferential area of the bearing of the camshaft 1 can be enclosed or received. The straightening force is thus introduced into the recess 21 of the borne prism 20 via two, where necessary even three, contact areas.

In accordance with another exemplary embodiment for a pressure element straightening head 19 is depicted in Figure 7. The pressure element straightening head 19 is provided with a pressure element that has a flat or spherical (not shown) surface via which the force is introduced into the area of the appropriate bearing. Analogous with the exemplary embodiment in accordance with Figure 6, the straightening force is also introduced at the location in the appropriate bearing of the camshaft 1 at which the greatest deflection, i.e. the greatest concentricity error, occurs. In this straightening method in accordance with Figures 6 and 7, the camshaft is thus “bent” by a certain value against the highest circumferential point in order to be able to compensate the existing concentricity error. The workpiece is stationary during straightening. The camshaft here is merely rotated via the C-axis into the radial position required for straightening, but then is held still in order to perform the straightening process.

These straightening methods are also suitable for straightening a camshaft such that the shaft is supported by steadies at the two outer bearings, instead of being held between centers. In such a case, the center steady 11 can be removed from contact so that the appropriate straightening device 6 or 19, 22 can be placed in contact with the center-most bearing of the camshaft for straightening the latter. This is depicted in principle in Figure 8. Such a straightening process is primarily frequently advantageous when the camshafts are to be ground in a "centerless" manner prior to cam shape grinding.

In both straightening methods, the straightening device is arranged on the grinding headstock and is preferably moved via the X-axis. The movement values are determined during both straightening methods using the camshaft geometry, the material, and also the gripping of the machine and also by the hardness of the cam surfaces. The movement values can be calculated in the machine CNC control, specifically with respect to the previously measured concentricity error. After straightening, concentricity errors of up to less than 0.01 mm can be attained on the center bearing. CBN grinding wheels are preferably used for grinding.

Legend

1 Camshaft
2 Bearing
3 Cam
4 Grinding machine
5 Concentricity measuring device
6 Straightening device
7 Grinding headstock
8 Machine bed

9, 10	Grinding wheels
11	Steadies
12	Workpiece headstock
13	Tailstock
14	Centers for gripping
15	First station of grinding machine
16	Second station of grinding machine
17	Roll straightening head
18	Swing-mounted rollers
19	Pressure element straightening head
20	Recess
22	Pressure element
23, 24	Grinding wheels
25	Dressing devices
28	Chuck